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Final Report: Can Heat Exchange Through the Rete Venosum of a Hand or Foot Improve Quality of Sleep?

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6. AUTHORS
H. Craig Heller, Dennis A. Grahn

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The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT
We developed technology that inserts heat into or removes heat from the body efficiently and rapidly. The technology exploits special circulatory adaptations of the non-hairy skin that include gated anastomoses between arteries and veins and veins that are arranged in a network. By applying a heat source or sink and a partial vacuum to these skin surfaces in the palms and the soles, it is possible to transfer significant amounts of heat efficiently. Our first task was to test whether we could use this technology to facilitate sleep in non-neutral thermal

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Report Title

Final Report: Can Heat Exchange Through the Rete Venosum of a Hand or Foot Improve Quality of Sleep?

ABSTRACT

We developed technology that inserts heat into or removes heat from the body efficiently and rapidly. The technology exploits special circulatory adaptations of the non-hairy skin that include gated anastomoses between arteries and veins and veins that are arranged in a network. By applying a heat source or sink and a partial vacuum to these skin surfaces in the palms and the soles, it is possible to transfer significant amounts of heat efficiently. Our first task was to test whether we could use this technology to facilitate sleep in non-neutral thermal environments. Our second task that was added later was to develop a multiuser heat removal system for the crew deck recovery shacks on aircraft carriers. We do not have positive results to report for task 1 as we were unable to acquire versions of the technology compatible with sleep. We did succeed in Task 2, but have not found clients to accept the technology for trials.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

D.A. Grahn, J. L. Dillon, H. C. Heller, 2009. Heat Loss Through the Glabrous Skin Surfaces of Heavily Insulated, Heat-Stressed Individuals.
Journal of Biomechanical Engineering. 131:071005-1-7

Number of Papers published in peer-reviewed journals: 1.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

(d) Manuscripts

Dennis A. Grahn,Vinh H. Cao, Christopher M. Nguyen, Mengyuan T. Liu, and H. Craig Heller Palm cooling between sets of resistive training improves work capacity and training response.

Number of Manuscripts: 1.00

Patents Submitted

Patents Awarded

Graduate Students

NAME	PERCENT_SUPPORTED
Maj. Joel Dillon	0.00
FTE Equivalent:	**0.00**
Total Number:	**1**

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
H. Craig Heller	0.00	No
FTE Equivalent:	**0.00**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
Ryan Fisicaro	0.00
Christopher Nguyen	0.00
Menguan T. Liu	0.00
FTE Equivalent:	**0.00**
Total Number:	**3**

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 3.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 3.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 3.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 3.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED	
Dennis A Grahn	0.60	No
Vinh Cao	0.40	No
FTE Equivalent:	**1.00**	
Total Number:	**2**	

Sub Contractors (DD882)

Inventions (DD882)

Final Report:

52776-LS -- Can Heat Exchange Through the Rete Venosum of a Hand or Foot Improve Quality of Sleep?

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FORWARD

The genesis of this project came from an inquiry from the ARO as a follow on to previous DARPA work funded through ARO (Enhancing The Conditioning, Endurance, And Recovery Of Military Personnel Through The Control Of Body Temperature: Rapid Deployment For Military Testing). That work was the development of a technology that could rapidly extract heat from the body or insert heat into the body through unique vascular structures in the palms of the hands and soles of the feet. The application that had been supported by that work was primarily the protection of military personnel when working at high levels with substantial body insulation and in high ambient temperatures. A second application was to facilitate physical conditioning. Both of these goals were realized with the development and commercial production of a device called "Core Control" or "RTX" for rapid thermal exchange. The company that produced these devices was AVAcore Technologies in Ann Arbor Michigan.

Previously our laboratory had studied the effects of ambient and body temperature on sleep in animals and humans. The question was therefore raised by ARO, could this new technology be used to enhance the sleep of military personnel exposed to non-neutral thermal conditions. We thought that this was a definite possibility and were eager to try, hence the initiation of this project.

Subsequently DARPA received a request from the Navy to provide RTX technology for testing in the deck shack of an aircraft carrier. The deck crew are exposed to stressful thermal conditions and have only brief periods of rest in the deck shack between launches and recoveries of aircraft. We were charged with making an installable, multiuser system for the USS Roosevelt. The funding for that effort was added to this contract.

This report covers both the sleep enhancement task and the prototyping of a personnel cooling system for ship use.

Task 1: Sleep enhancement.

Our previous work and the work of others had shown clearly that ambient and body temperatures have strong effects on sleep quality and sleep amounts in rodents and in humans (1). Animal work demonstrated that manipulations of core temperature could partially compensate for stressful ambient temperatures, but this question could not be addressed in humans for lack of a non-invasive method for altering core temperature. The RTX technology clearly had the ability to return core temperature to the normal range when subjects were working or resting in a thermally stressful environment (2, 3, 4). Thus it seemed logical that mitigating slight deviations in core temperature due to non-optimal thermal environments during sleep should improve the quality of sleep. The challenge that we faced, however, was the development of an embodiment of the RTX technology that would be usable on a sleeping subject. The commercially available devices from AVAcore were hard, bulky, uncomfortable for long term use, and definitely not conducive to sleep. We did not have in this contract funds for new product development, but we anticipated a solution to this problem to come from AVAcore Technologies.

At the time we began this contract, AVAcore executed a subcontract to Gaymar Industries to develop, produce, and sell a Core Control system for perioperative use. Since such a system would enable our project goal, we engaged our time in working with Gaymar engineers to design and test new devices. Unfortunately we were not in a position to control the direction of this technology development project, and our advice was frequently ignored. As a result, the first system developed and given to us to test was totally unsatisfactory. The foot interface devices were rigid and would not have been conducive for normal sleep. Also, the thermal exchange contact surface was not optimal because it did not conform to the shape of the foot. That problem also influenced the temperature control system since the feedback circuit depended on 6 point measurements on the heat exchanger, and if the skin was not in contact with one or more of those points, the recorded exchange surface temperature was greater than the actual contact surface temperature. The engineering firm that produced this prototype was fired by Gamar.

The second device development attempt was made by Gaymar engineers. We were optimistic that this change would enable us to have more influence over the design process. We had some success in getting them to focus on soft materials that would mold to the foot and would not fix the foot in a rigid structure. However, commercial considerations eventually took over, and the corporate decision was to pursue a design that we determined would not work rather than going through another design cycle. We were proved to be correct in our assessment, the chosen design did not work in clinical trials, and Gaymar cancelled the project. Thus, our efforts were non-productive and we never had equipment that would enable the proposed experiments described in our original SOW.

We did achieve a number of subtasks that would enable this project to go forward once appropriate equipment was available. We tested several ambulatory EEG monitoring systems and we established a sleep test facility. We also made progress in prototyping a wearable, flexible RTX system for use on the hands of dismounted soldiers. The temperature and vacuum controls on this system are contained in a backpack hydration system such as CamelBack. The elements of this system could be used for a sleep system.

In summary, however, I have to report that we were unsuccessful in achieving the ultimate goal of this task – assessing the ability to enhance sleep in non-optimal thermal environments.

Task 2: Prototyping and Testing a Multi-User RTX System for Heat Stress Mitigation of the Deck Crew of an Aircraft Carrier.
Our problems and success in this task are exactly the opposite of those in Task 1. We were able to build prototype systems, but have been unable to test them in the intended application environment.

A Navy Rear Admiral associated with the USS Roosevelt Task Force when it was deployed in the Gulf, requested DARPA to provide a version of the RTX technology to mitigate the heat stress of the deck crew responsible for launching and recovering aircraft. These individuals wear protective gear, are exposed to the sun and heat of the deck, and the heat from jet exhaust. Their periods for recovery are brief and therefore they can only retire to the "deck shack" that is just off the main launch and recovery deck. We were charged with developing an installable, multiuser RTX cooling system for the deck shack. We designed the system, obtained COTS parts where possible, and built hand interface units that would be cleanable and disposable. As an interim measure while this design, construction, and testing was underway, we sent two commercial RTX systems to the Roosevelt for immediate use. Their use was overseen by the medical officer and reports were that they were successful in treating cases of extreme heat stress. Because they were limited to these two units that did not have disposable parts, they did not put them into general use.

By the time we had built the multiuser, installable system and bench tested it. The Roosevelt was returning from the Gulf. It was relieved by the USS Eisenhower. The RTX units were transferred to the Eisenhower (we were told) and the responsibility for taking over the testing of the deck shack system was also transferred. However, in spite of multiple tries, we were unable to establish communication with the named individuals on the Eisenhower. DARPA was informed of this, and still, no avenue was established for getting the new equipment to the Eisenhower,

Although our contract was to produce one unit, we produced three. They are all operational but have not been deployed. We are now seeking other venues for implementing these systems, and contacts have been made at Nellis AFB for installation on the flight line. This implementation would enable performance and effectiveness assessment. If successful, the way would be clear for engineering for production.

In summary, we were only partially successful in Task 2. We designed and built the requested equipment, but have been unable to test it in a military application.

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3. Grahn, D.A., Cao, V.H., and Heller, H.C. (2005) Heat Extraction through the palm of one hand improves aerobic exercise endurance in a hot environment. J. App. Physiol 99:972-978
4. Grahn, D.A., Dillon, J.L., Heller, H.C. (2009) Enhancing heat loss through the glabrous skin surfaces of heavily insulated individuals. J. of Biomech. Eng. 131:071005-1-7